

Validation of ice formation in cloud resolving models via remote sensing

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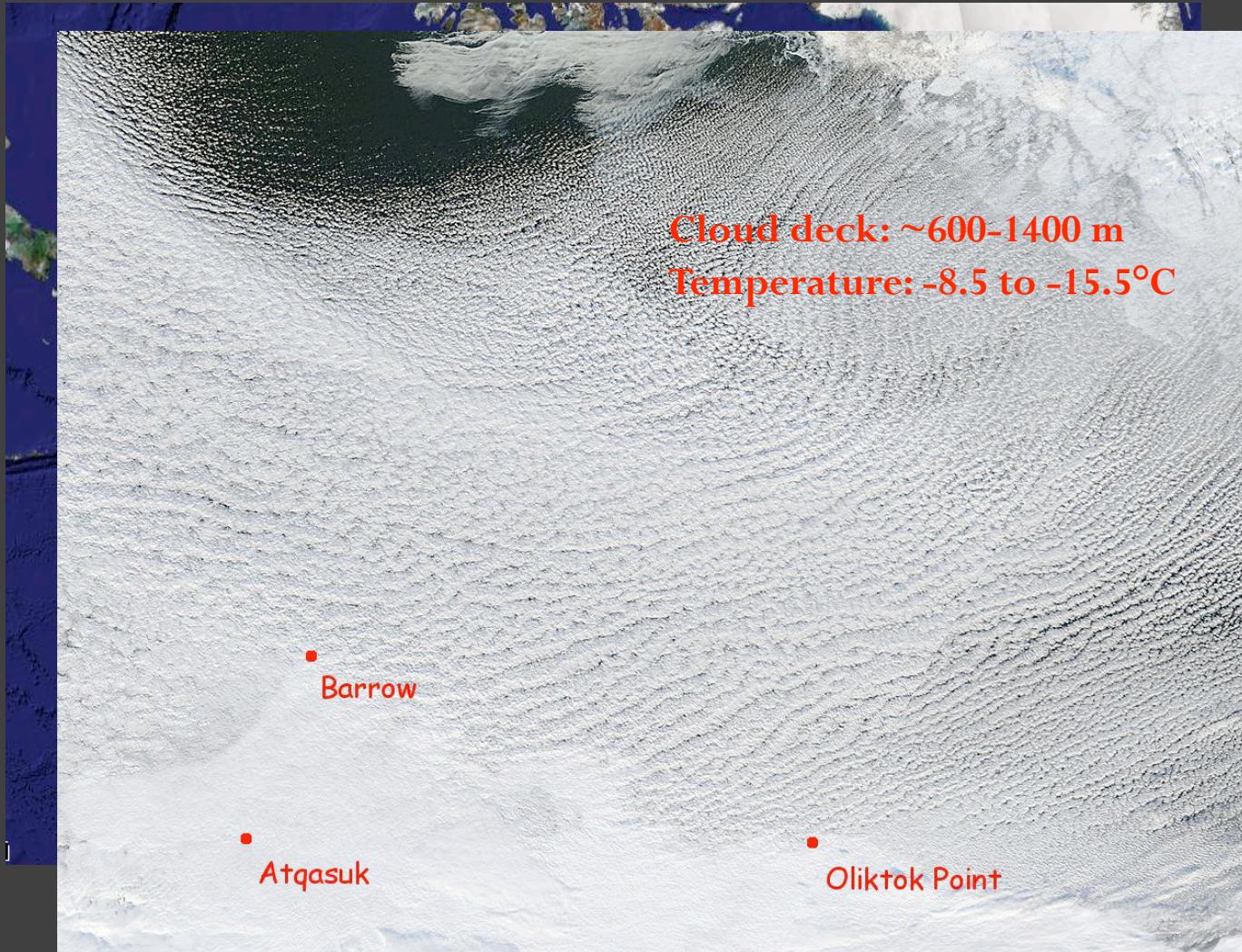


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Outline

- Case study description
- Radar and Lidar measurements
- Ice formation processes
- Simulations
 - Cloud resolving model
 - Lidar and Radar simulations
- Comparison of simulations and measurements
 - As a function of time/space
 - In contoured frequency by altitude diagrams (CFADSS)
 - In Taylor diagram
 - Skill scores

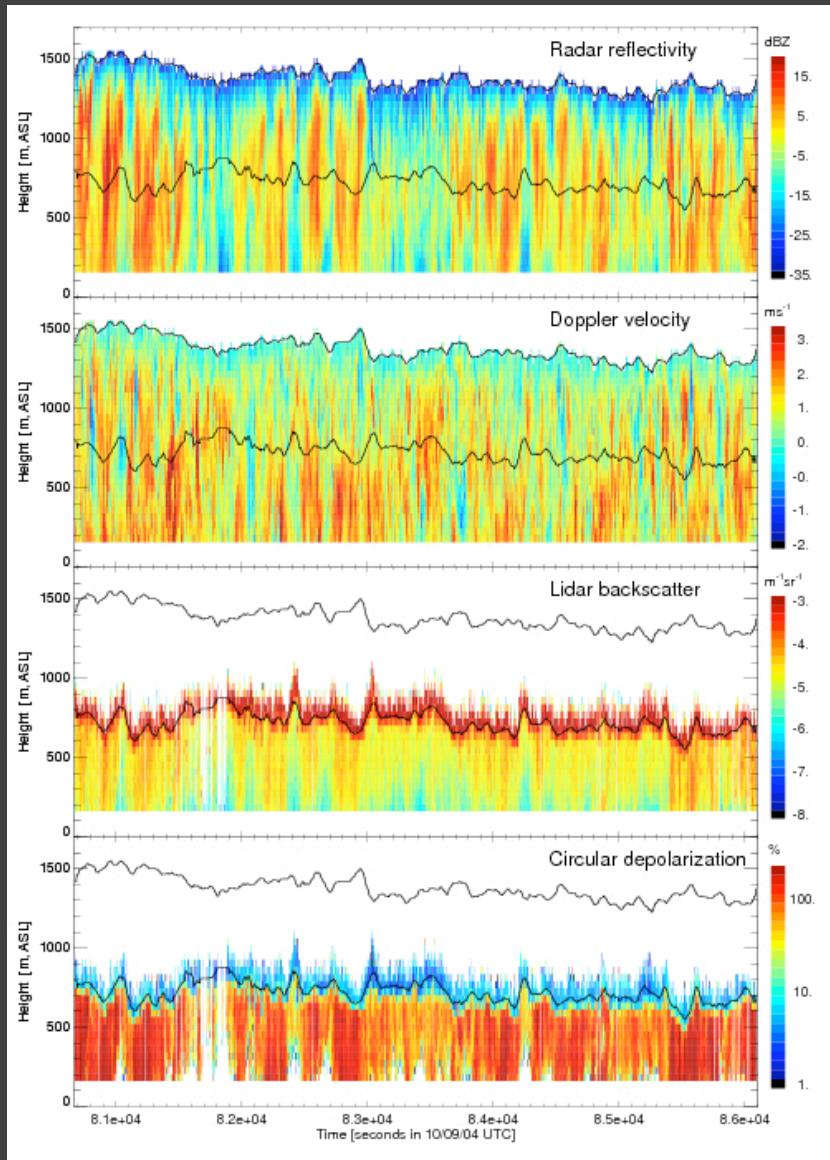
Measurements at Barrow, Alaska, October 9th & 10th, 2004



Measurements at Barrow: Instruments

- Millimeter Cloud Radar (MMCR)
 - 35 GhZ Intensity (dBZ)
 - Sensitive to large droplets and ice
 - Doppler velocity (m/s)
 - Particle fall velocity weighted by Intensity
- (Arctic) high spectral resolution lidar (AHSRL)
 - 532 nm Backscatter coefficient ($m^{-1}sr^{-1}$)
 - Size distribution droplets and ice
 - Circular depolarization
 - Particle shape or roundness
 - High depolarization indicates (non-spherical) ice crystals

MMCR Radar and AHSRL Lidar measurements



Ice formation & multiplication in clouds

- Homogeneous drop freezing (-36° C)
- Heterogeneous nucleation
 - Contact nucleation: $\text{drop} + \text{IN}_{\text{aer}} = \text{ice}$ ($-4^\circ > T > -14^\circ$)
 - Condensation nucl: $\text{vapor} + \text{IN}_{\text{aer}} = \text{ice}$ ($-8^\circ > T > -22^\circ, S_{\text{liq}} > 0$)
 - Deposition nucl.: $\text{vapor} + \text{IN}_{\text{aer}} = \text{ice}$ ($-10^\circ > T, S_{\text{ice}} > 0$)
 - Immersion nucl.: $\text{drop} + \text{IN}_{\text{drop}} = \text{ice}$ ($-10^\circ > T > -24^\circ$)
- Also multiplication possible such as
 - Rime splintering: $-3^\circ > T > -8^\circ$
- Very little ice formed due to low IN concentrations ($< 0.2 \text{ L}^{-1}$)

To increase ice formation

- Slower ice fall velocities and increase multiplication
- Increase concentrations of IN to 3 orders of magnitude higher than measured
- Constant surface source of IN (6 L^{-1})

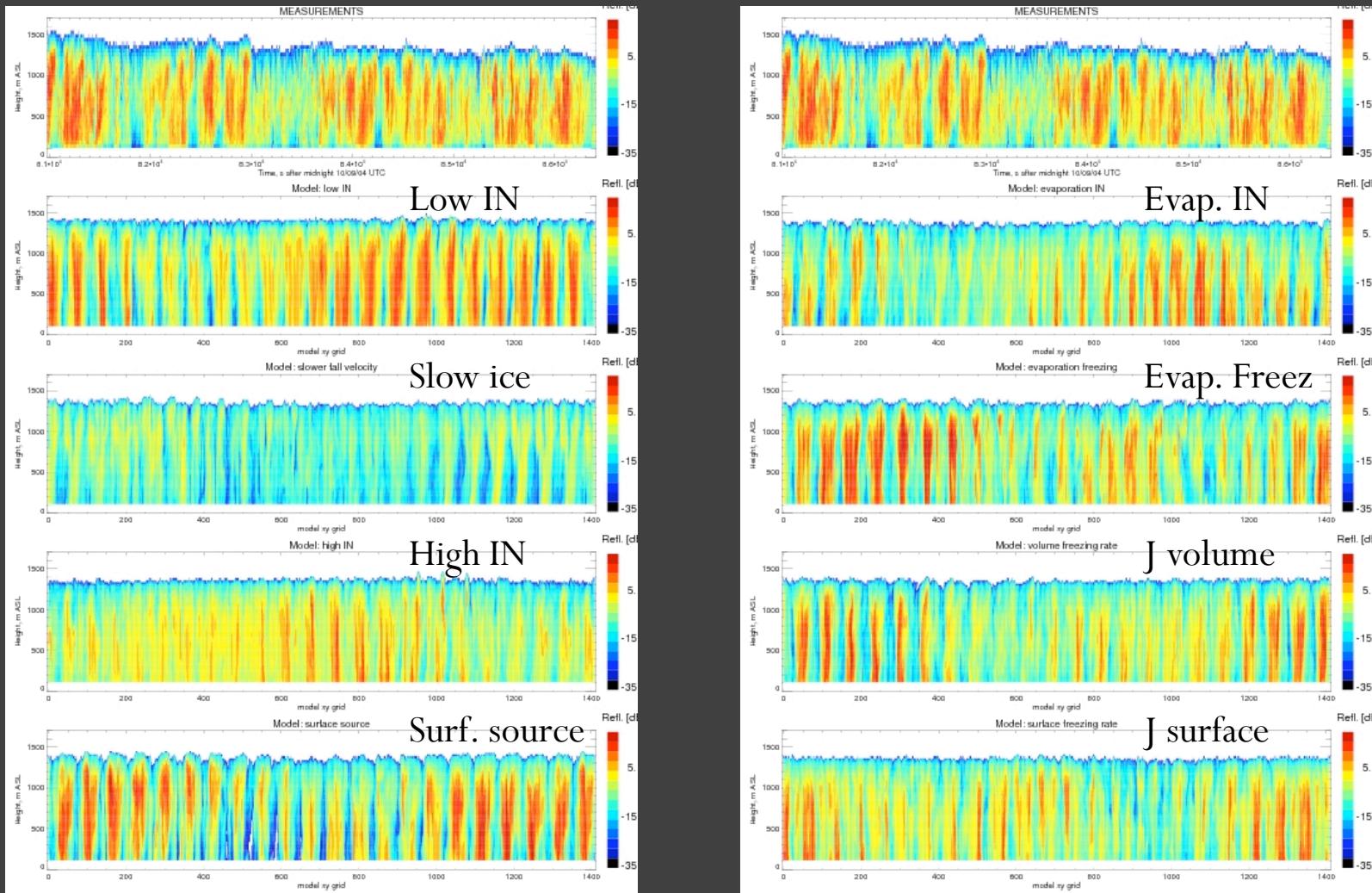
Other ice formation processes

- Evaporation nuclei: residuals of evaporating drops become IN
(Beard 1992)
 - Possibly oceanic particles form INs due to in-drop chemistry
 - One in every $10^4 - 10^5$ drops residuals form IN
- Evaporation freezing: some evaporating drops freeze instantly
(Cotton and Field 2002)
 - Possibly long-chain organic compounds formed in the drops
- Arbitrary freezing rates (J) of cloud droplets with $T < 0$
 - Rate per unit volume or surface area
 - Could be caused by organic surface films around drops

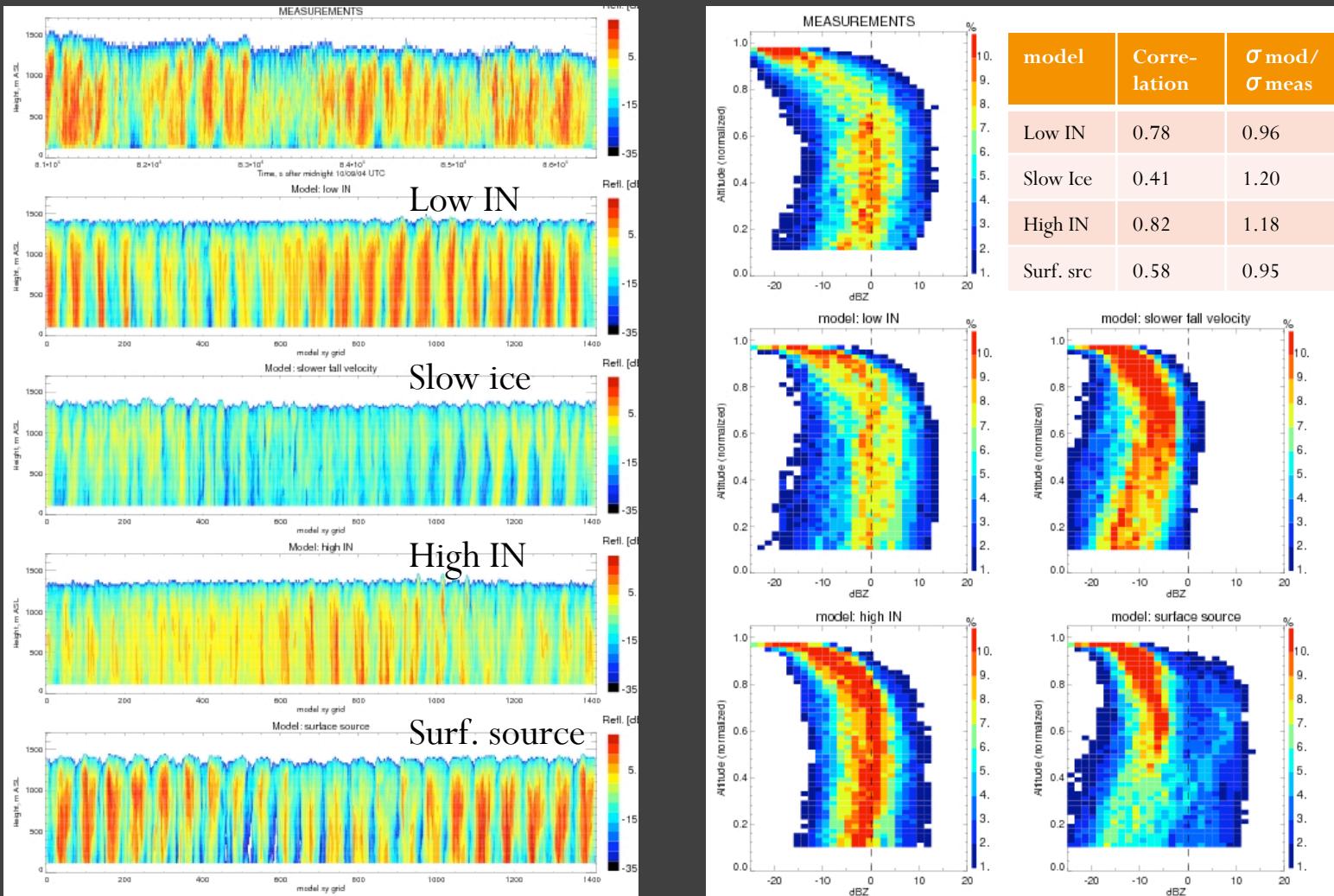
Simulations

- DHARMA model (Ackerman et al, Nature, 2000)
 - Large eddy simulation model
 - 3.2 x 3.2 x 2 km box, 64 x 64 x 96 grid
 - Size resolved microphysics:
 - 20 size bins each for ice and liquid
- Radiative transfer
 - Radar calculations with Quickbeam (Haynes et al 2007) assuming MIE
 - Lidar calculations assume
 - Mie theory for liquid
 - Randomly distorted plates for ice particles (using geometrical optics)
 - RT calculations are made for 200 size bins
- Forward calculations can be compared directly to measurements:
no retrieval step in between

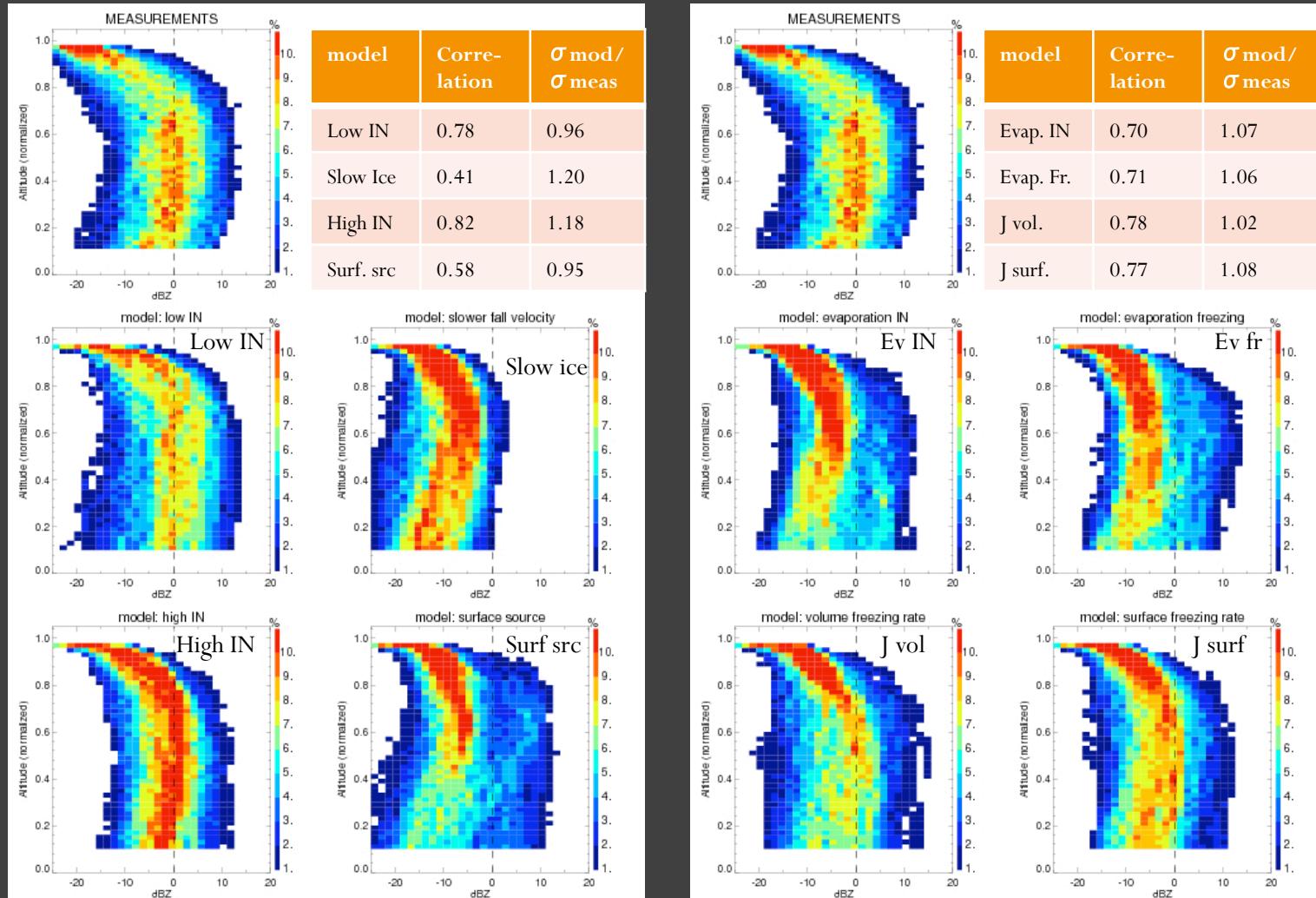
Results: Radar reflectivity



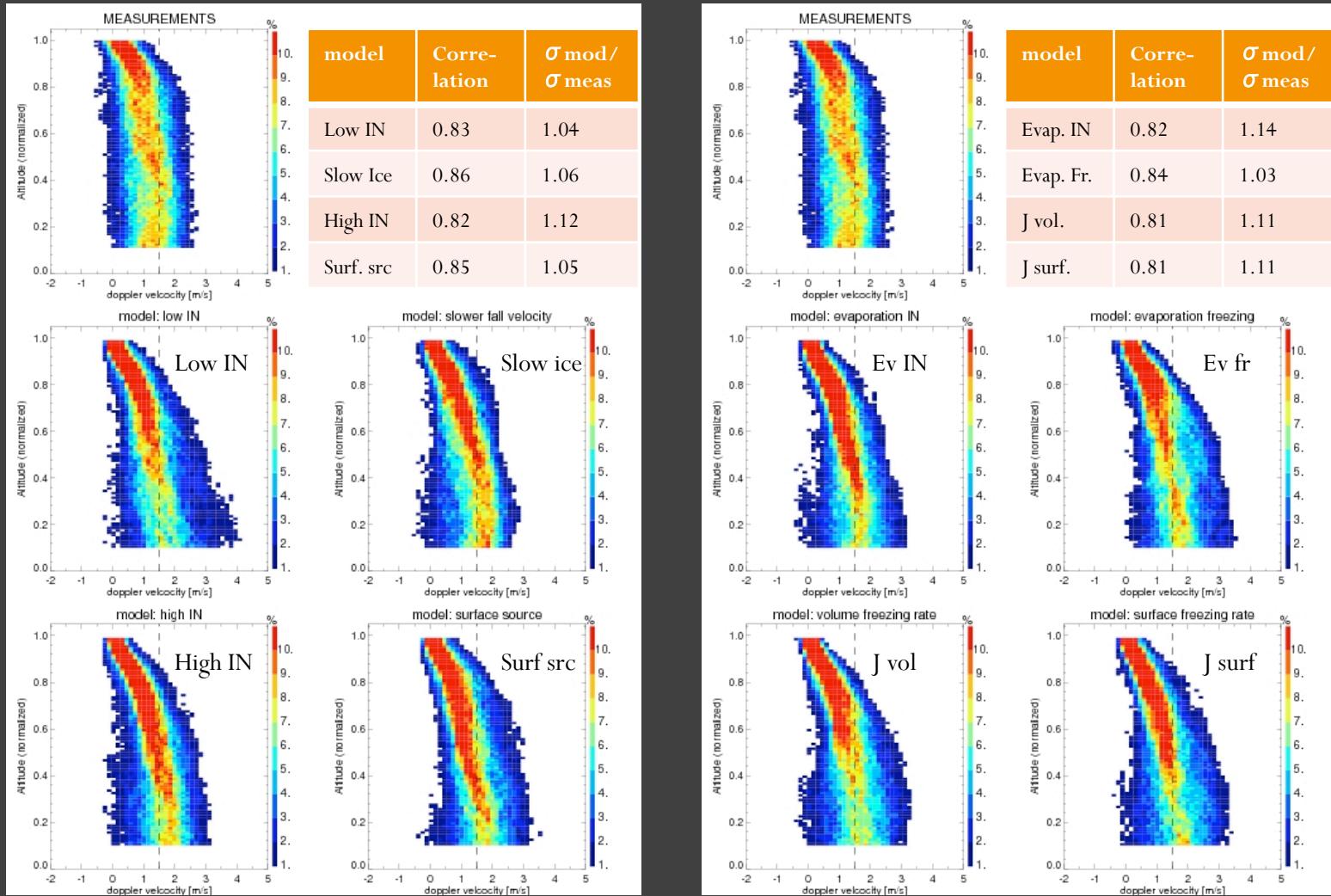
Results shown as Cfads



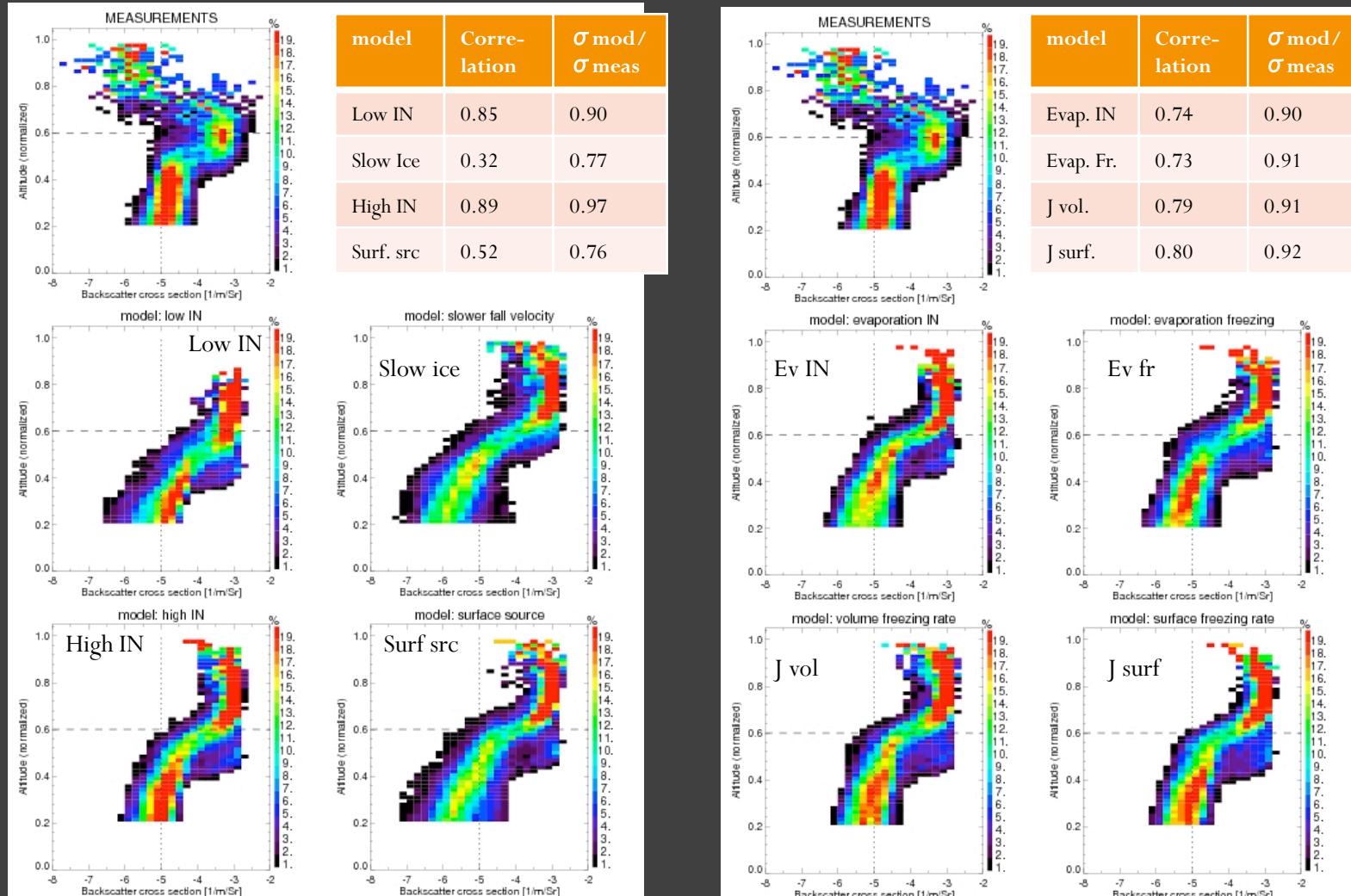
Results: RADAR reflectivity



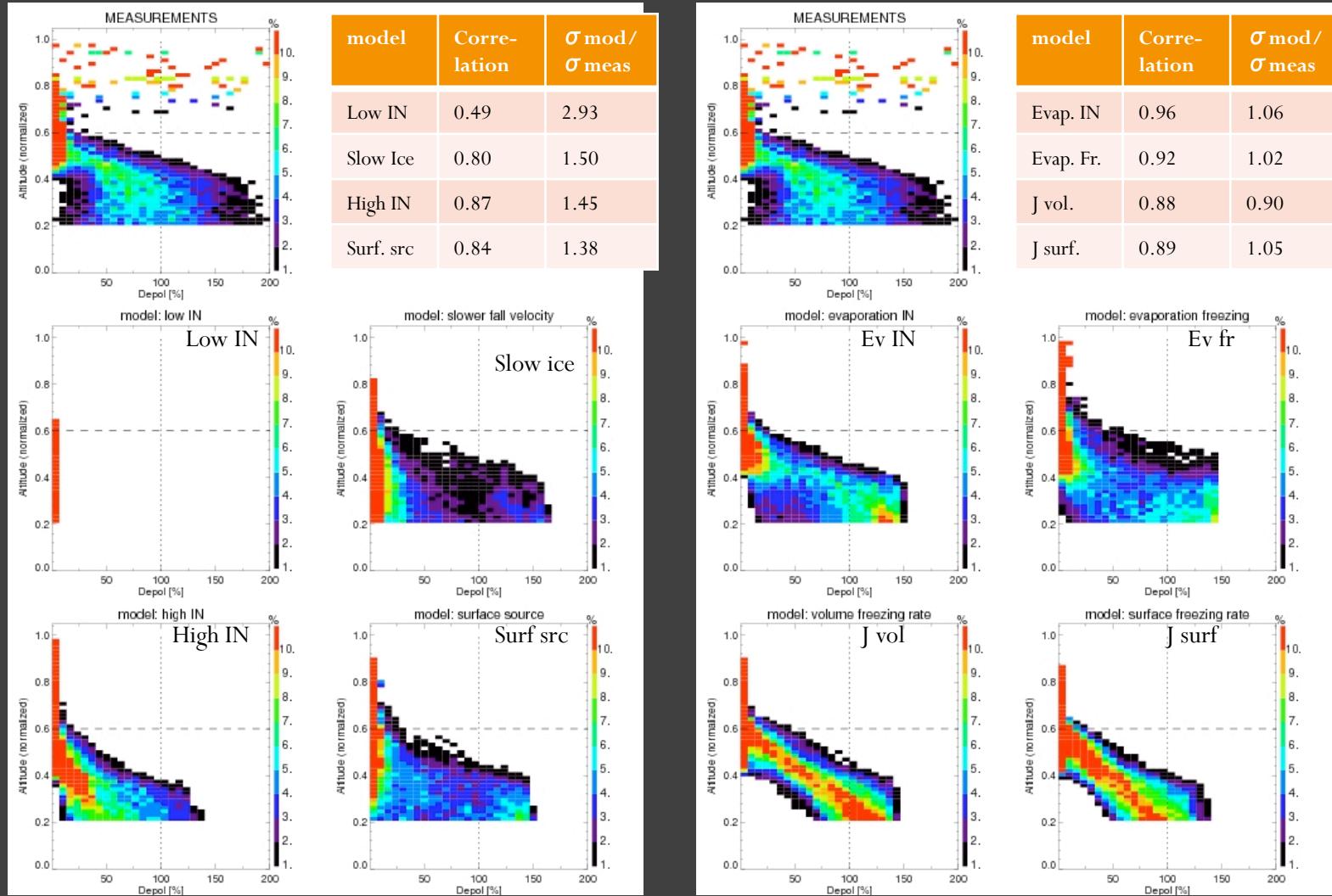
Results: RADAR Doppler velocity



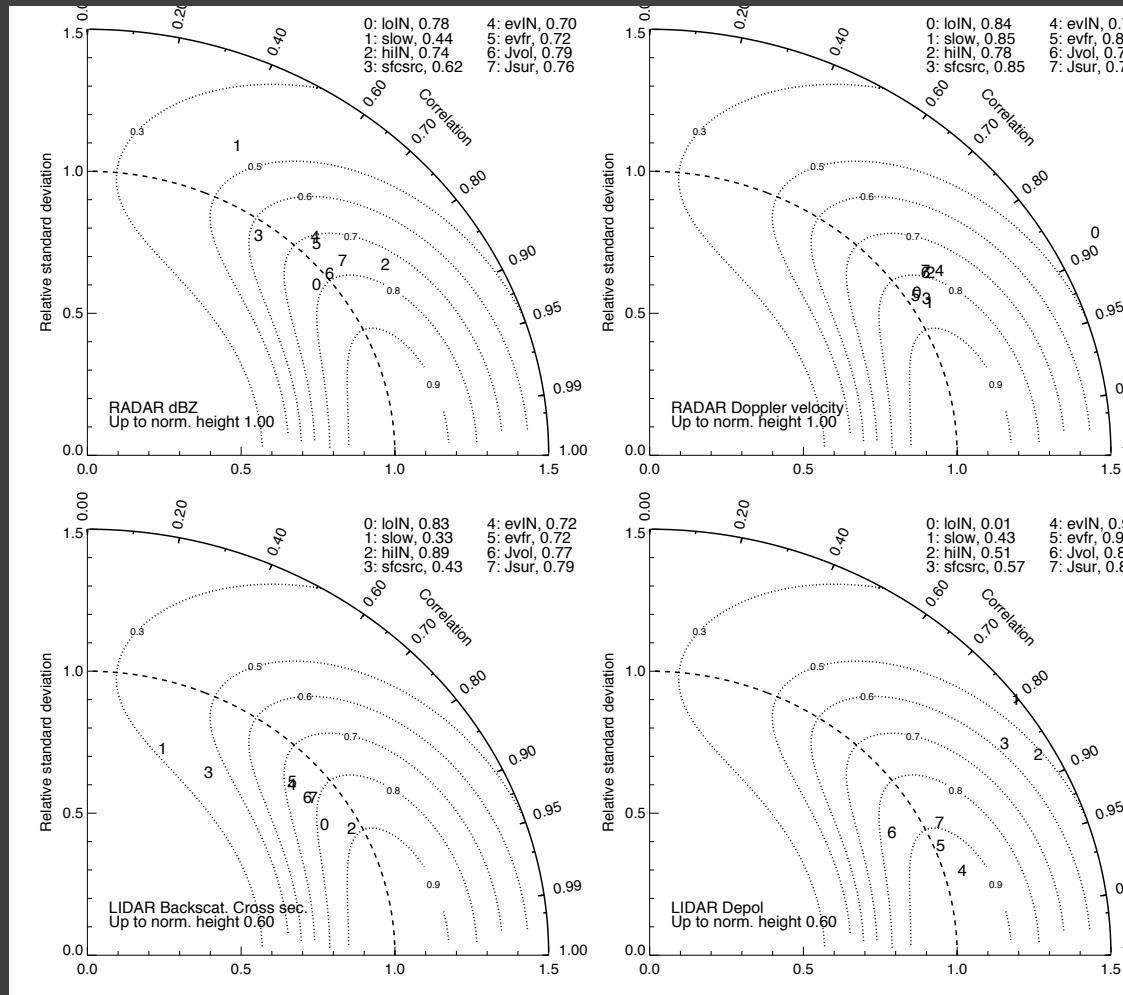
Results: LIDAR backscatter



Results: LIDAR depolarization



Results in Taylor diagram (taylor,2001)



- skill scores:

$$S = 2^6(1 + \text{Corr})^2 / (\sigma + 1/\sigma)^8$$

Average scores:

- | | | |
|---|-----------|-------|
| 1 | J surf: | 0.805 |
| 2 | Evap. fr: | 0.802 |
| 3 | J vol: | 0.797 |
| 4 | Evap IN: | 0.786 |
| 5 | High IN: | 0.731 |
| 6 | Surf src: | 0.615 |
| 7 | Low IN: | 0.614 |
| 8 | Slow ice: | 0.513 |

Summary

- Direct simulation of remote sensing measurements from cloud resolving model results is powerful validation tool
- Simulations with measured low IN concentrations and conventional ice formation processes do not compare well to measurements (especially depolarization)
- Also simulations using slower fall velocities or a surface source of IN do not compare well to measurements
- Best candidates are: Evaporation IN, evaporation freezing, and increased droplets freezing rate